Received 16 November 1984; accepted 14 January 1985.

1. Weatherall, D. J. *The New Genetics and Clinical Practice* (Nuffield Provincial Hospitals Trust, London, 1982).
2. Botstein, D., White, R. L., Skolnick, M. & Davis, R. *Am. J. hum. Genet.* **32**, 314-331 (1980).
3. Drayna, D. *et al. Proc. natn. Acad. Sci. U.S.A.* **81**, 2836-2839 (1984).
4. Murray, J. M. *et al. Nature* **300**, 69-71 (1982).
5. Gusella, J. F. *et al. Nature* **306**, 234-238 (1983).
6. Cavanee, W. K. *et al. Nature* **305**, 779-784 (1983).
7. Fearson, E. R., Vogelstein, B. & Feinberg, A. P. *Nature* **309**, 176-178 (1984).
8. Koufos, A. *et al. Nature* **309**, 170-172 (1984).
9. Orkin, S. H., Goldman, D. S. & Sallan, S. E. *Nature* **309**, 172-174 (1984).
10. Jeffreys, A. J. *Cell* **18**, 1-10 (1979).
11. Cooper, D. N. & Schmidtke, J. *Hum. Genet.* **66**, 1-16 (1984).
12. Ewens, W. J., Spielman, R. S. & Harris, H. *Proc. natn. Acad. Sci. U.S.A.* **78**, 3748-3750 (1981).
13. Barker, D., Schafer, M. & White, R. *Cell* **36**, 131-138 (1984).
14. Wyman, A. & White, R. *Proc. natn. Acad. Sci. U.S.A.* **77**, 6754-6758 (1980).
15. Bell, G. I., Selby, M. J. & Rutter, W. J. *Nature* **295**, 31-35 (1982).
16. Higgs, D. R., Goodbourn, S. E. Y., Wainscoat, J. S., Clegg, J.B. & Weatherall, D. J. *Nucleic Acids Res.* **9**, 4213-4224 (1981).
17. Proudfoot, N. J., Gil, A. & Maniatis, T. *Cell* **31**, 553-563 (1982).
18. Goodbourn, S. E. Y., Higgs, D. R., Clegg, J. B. & Weatherall, D. J. *Proc. natn. Acad. Sci. U.S.A.* **80**, 5022-5026 (1983).
19. Capon, D. J., Chen, E. Y., Levinson, A. D., Seeburg, P. H. & Goeddel, D. V. *Nature* **302**, 33-37 (1983).
20. Weller, P., Jeffreys, A. J., Wilson, V. & Blanchetot, A. *EMBO J.* **3**, 439-446 (1984).
21. Vieira, J. & Messing, J. *Gene* **19**, 259-268 (1982).
22. Loenen, W. A. M. & Brammar, W. J. *Gene* **20**, 249-259 (1980).
23. Dover, G. *Nature* **299**, 111-117 (1982).
24. Morton, N. E. *Outline of Genetic Epidemiology*. (Karger, Basel, 1982).
25. Chang, L.-Y. E. & Slightom, J. L. *J. molec. Biol.* (in the press).
26. Goodman, M., Koop, B. F., Czelusniak, J., Weiss, M. & Slightom, J. L. *J. molec. Biol.* (in the press).
27. Harris, S., Barrie, P. A., Weiss, M. L. & Jeffreys, A. J. *J. molec. Biol.* (in the press).
28. White, C. T., Hardies, S. C., Hutchison, C. A. & Edgell, M. H. *Nucleic Acids Res.* **12**, 751-766 (1984).
29. Smith, G. R., Kunes, S. M., Schultz, D. W., Taylor, A. & Triman, K. L. *Cell* **24**, 429-436 (1981).
30. Smith, G. R. *Cell* **34**, 709-710 (1983).
31. Ewens, W. J. *Theor. Pop. Biol.* **3**, 87-112 (1972).
32. Ewens, W. J. *Mathematical Population Genetics* (Springer, Berlin, 1979).
33. Dretzen, G., Bellard, M., Sassone-Corri, P. & Chambon, P. *Analyt. Biochem.* **112**, 295-298 (1981).
34. Maxam, A. M. & Gilbert, W. *Meth. Enzym.* **65**, 499-560 (1980).
35. Southern, E. M. *Meth. Enzym.* **68**, 152-176 (1980).
36. Jeffreys, A. J. *et al. Cell* **21**, 555-564 (1980).
37. Messing, J. & Vieira, J. *Gene* **19**, 269-276 (1982).
38. Sanger, F., Nicklen, S. & Coulson, A. R. *Proc. natn. Acad. Sci. U.S.A.* **74**, 5463-5467 (1977).
39. Biggin, M. D., Gibson, T. J. & Hong, H. F. *Proc. natn. Acad. Sci. U.S.A.* **80**, 3963-3965 (1983).
40. Duckworth, M. L. *et al. Nucleic Acids Res.* **9**, 1691-1706 (1981).
41. Renz, M. & Kurz, C. *Nucleic Acids Res.* **12**, 3435-3444 (1984).

LETTERS TO NATURE

Cometary impacts, molecular clouds, and the motion of the Sun perpendicular to the galactic plane

Patrick Thaddeus*† & Gary A. Chanan†

* Goddard Institute for Space Studies, 2880 Broadway, New York, New York 10025, USA
† Columbia Astrophysics Laboratory, Department of Physics, Columbia University, New York, New York 10027, USA

Raup and Sepkoski[1] have presented evidence from marine fossils for a 26-Myr periodicity in the occurrence of mass extinctions. Using the same data Rampino and Stothers[2] obtained a different period, 30 ± 1 Myr, which agrees with the 33 ± 3-Myr half-period for the vertical oscillation of the Solar System about the plane of the galaxy[3]. To explain this agreement they suggest[2] that encounters with molecular clouds perturb the Sun's family of comets, causing many to enter the inner Solar System where one or more collide with the Earth; the cloud encounter rate is modulated at twice the oscillation frequency, because the number density of clouds peaks at the galactic plane at the midpoint of the solar oscillation crossed by the Solar System twice per period. Notwithstanding an apparent objection to this that the most recent extinctions are not in phase with the solar oscillation[4], their model, given its stochastic nature, can accommodate a few events with large phase discrepancies. The degree of modulation is crucial: it depends on the scale height of the population of molecular clouds relative to the amplitude of the solar motion and tends to zero if this ratio is large and encounters are entirely random. Here we present data from CO surveys of molecular clouds both within and beyond the solar circle, which permit explicit calculation of the strength of the modulation. The cloud layer near the Sun is too extended and, as a consequence, the modulation of cloud encounters is too weak for a statistically significant period to be extracted from the nine extinctions analysed by Rampino and Stothers.

Although we assume a gaussian distribution of clouds with z, the distance from the galactic plane, our conclusions do not depend sensitively on this assumption and remain essentially unchanged if an exponential or other plausible distribution function is assumed instead. The empirical parameter crucial to the mechanism of Rampino and Stothers is, then, the ratio of the amplitude of the solar oscillation z_0 to the half-thickness at half-density $z_{1/2}$ of the distribution of local molecular clouds. One is not free to treat z_0 as a free parameter; it is fixed by (1) the requirement that the period, T, of the oscillation must be 60 Myr, twice the putative extinction period, (2) the circumstance that the Sun is now close to the galactic plane so its z component of velocity, $v_\perp = 7.4\ \mathrm{km\,s^{-1}}$, is essentially that at $z=0$, and (3) the constraint of simple harmonic oscillation[5], $z_0 = v_\perp T/2\pi = 72$ pc.

Because of the large scatter and uncertainty in the distance of local clouds, there is, as yet, no reliable measurement of $z_{1/2}$ in the vicinity of the sun (that is, within ~1 kpc) from CO or other molecular cloud surveys, but there are good measurements from several large-scale CO surveys of $z_{1/2}$ as a function of galactocentric distance for distant clouds both within the solar circle and beyond. Figure 1 summarizes the survey data. All the CO surveys are consistent with a gradual increase of $z_{1/2}$ with R, proportional approximately to $R^{0.5}$ and a value of $z_{1/2}$ at the solar circle of 85 ± 20 pc (uncertainty 1 s.d.) which we will adopt here for the solar vicinity. Local observations of clouds at known distances are consistent with this value, but are inconsistent with a population of clouds significantly more compressed to the galactic plane. The well-known large concentrations of molecular clouds in Orion and Monoceros[6], for example, representing a significant fraction of local clouds by mass, lie 150–200 pc from the plane, or about twice our adopted $z_{1/2}$.

To calculate the encounter rate as the solar system oscillates sinusoidally through a gaussian distribution of clouds, we may safely neglect the small present displacement of the Sun from the galactic plane. The solar velocity components parallel and perpendicular to the plane are then $v_\parallel = v \cos b = 18.5\ \mathrm{km\,s^{-1}}$ and $v_\perp = v \sin b \sin \omega t = 7.4\ \mathrm{km\,s^{-1}} \sin \omega t$, where $v = 20\ \mathrm{km\,s^{-1}}$ is the present solar motion relative to local stars and interstellar matter[7], $b = 22°$, the galactic latitude of the solar apex[7], and $\omega_0 = 2\pi/60\ \mathrm{Myr^{-1}}$. Because of the low latitude of the apex, the solar speed as a function of time, $v(t) = v_\parallel(1+0.164\cos^2\omega_0 t)^{1/2} \approx v_\parallel(1+0.082\cos^2\omega_0 t)$, is always large with respect to the random motion of the clouds, which may be neglected. Letting $\zeta = \ln 2\ z_0^2/z_{1/2}^2$, the number of encounters (extinctions) per unit time is then simply

$$r(t) = n(z(t))v(t)\sigma = C(1+0.082\cos^2\omega_0 t)\exp(-\zeta\sin^2\omega_0 t) \qquad (1)$$

an explicit function of time at a given ζ with no free parameters except the constant of normalization $C \equiv n_0 v_\parallel \sigma$, where n_0 is the in-plane number density of clouds and σ the encounter cross section. It is tacitly assumed that the encounters are short range, that is, that the impact parameter b is small with respect to $z_{1/2}$; the effect of long range encounters is clearly to reduce the modulation (see below).

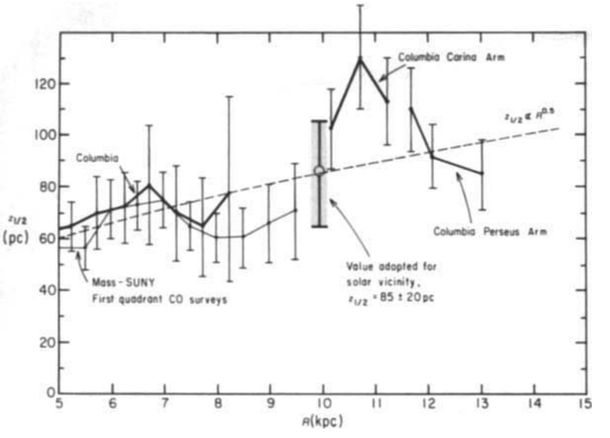

Fig. 1 Half-thickness of the distribution of molecular clouds with distance from the galactic plane, as a function of distance from the centre of the Galaxy, determined by the Massachusetts-Stony Brook (ref. 11) and Columbia CO surveys.

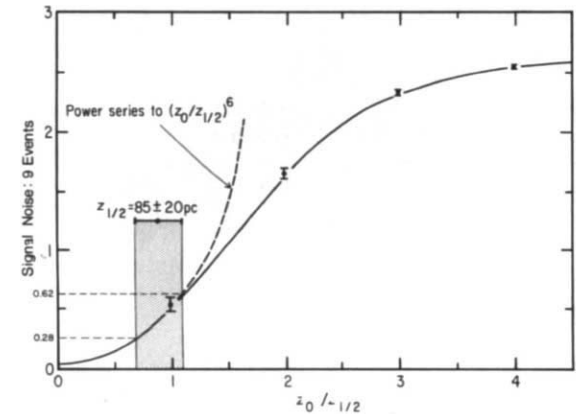

Fig. 2 Signal-to-noise of the leading Fourier component at $2\omega_0$ for nine events, as a function of the ratio of the amplitude of the solar oscillation to the half-thickness of the molecular cloud disk. The four points with vertical error bars indicate the results of a check on equation (4) with the Monte-Carlo code used to produce Fig. 3.

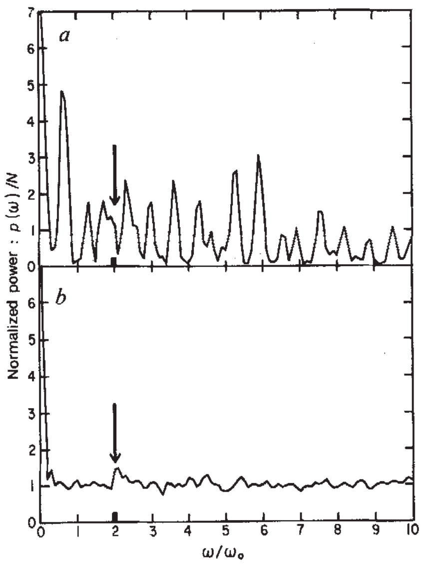

Fig. 3 Monte-Carlo calculation for $z_0/z_{1/2}=1$ of the power spectrum of random events drawn from the distribution given by equation (1). *a*, Nine events, the number of mass extinctions analysed by Rampino and Stothers[2]; *b*, the average of 100 such spectra, showing the small expectation value $\langle p(R)\rangle-\langle p(0)\rangle$ of the nine-event peak (short vertical bar at $\omega/\omega_0=2$).

We now wish to calculate the power spectrum $p(\omega)$ for a sample of N encounters drawn from this distribution with respect to time, and, specifically, the signal strength of the leading Fourier component at $2\omega_0$ relative to the shot noise, that is, the purely statistical fluctuations in the absence of modulation. We define the compex Fourier amplitude as

$$A(\omega)=\sum_{i=1}^{N}\exp(\mathrm{j}\omega t_i)\equiv\sum_{i=1}^{N}(x_i+\mathrm{j}y_i) \tag{2}$$

where the t_i are the encounter times and define the power spectrum as usual as $p(\omega)=|A(\omega)|^2$. The first and second moments of $A(2\omega_0)$ are readily calculated. We may take $\langle y\rangle=0$ without loss of generality. Then, $\langle x\rangle=\int r(t)\cos 2\omega_0 t\,\mathrm{d}t/\int r(t)\,\mathrm{d}t\equiv R$, $\langle x^2\rangle=\int r(t)\cos^2 2\omega_0\,\mathrm{d}t/\int r(t)\,\mathrm{d}t\equiv S^2$ and $\langle y^2\rangle=1-S^2$, and the variances corresponding to the second moments are $\sigma_x^2=S^2-R^2$ and $\sigma_y^2=1-S^2$. The expectation value of the power at $2\omega_0$ is then

$$\langle p(R)\rangle=N^2\langle x\rangle^2+N\sigma_x^2+N^2\langle y\rangle^2+N\sigma_y^2=N(N-1)R^2+N \tag{3}$$

Care is required in calculating the signal-to-noise ratio (S/N) as the statistical fluctuations in the absence of modulation (that is, signal) are distributed normally in A but exponentially in p; the expression for this ratio in the absence of knowledge of the phase of the signal is

$$\mathrm{S/N}=\left[\frac{\langle p(R)\rangle-\langle p(0)\rangle}{\langle p(0)\rangle}\right]^{1/2}=\sqrt{N-1}\,R \tag{4}$$

The normalized Fourier transform R in equation (2) may be conveniently approximated analytically when ζ is not too large, by expanding the exponential in equation (1) in a power series, or it may be readily evaluated numerically at all ζ. The S/N ratio from both methods for $N=9$ events is shown in Fig. 2. For the observed thickness of the population of molecular clouds at the solar circle, S/N is evidently so small, 0.45 ± 0.17, that a statistically significant determination of the underlying modulation period cannot be obtained.

A graphic demonstration of this conclusion and a useful check as well of the analytical theory (Fig. 2), has been obtained by Monte Carlo simulation. The top of Fig. 3 shows the power spectrum derived numerically from a sample of nine random events drawn from the distribution of equation (1); the signal is clearly swamped by the purely statistical fluctuations, that is, the shot noise spikes. The expectation value of the peak power can be obtained by averaging together 100 such (independent) spectra, as in the bottom panel of Fig. 3; its smallness compared with the noise spikes in the top panel is evident. To express this result another way, scaling from equation (4) we find that even a relatively modest signal characterized by $\mathrm{S/N}=3$ would require not nine extinction events, but >300.

Given that our assumption, that the encounters between the Solar System and molecular clouds are short range with respect to $z_{1/2}$, is an oversimplification, a significantly larger number of events may actually be required. Because of the fairly flat mass spectrum of molecular clouds[8,9], the most important encounters are likely to be with large clouds or cloud complexes whose mass exceeds $1\times10^5\,M_\odot$ and these will occur mainly at impact parameters exceeding 50 pc (ref. 10). The result of such distant encounters is to increase significantly the effective thickness of the molecular cloud layer, which, by Fig. 2, further reduces the S/N ratio in the power spectrum of the peak at $2\,\omega_0$. Because of the breakdown of the impulsive approximation at large impact parameters, exactly how many additional events are required when this effect is taken into account is not clear, but we estimate that it could be a factor $\geqslant 10$. Our conclusion is, therefore, that at least 300 mass extinctions and possibly many more, as opposed to the nine analysed by Rampino and Stothers, are required to yield statistically significant evidence for the oscillation of the Solar System about the plane of the galaxy under the molecular cloud hypothesis. It follows that if a periodicity does exist in the data, it is highly unlikely to result from encounters between the Solar System and molecular clouds.

We thank T. M. Dame, E. Gottlieb and D. A. Grabelsky for the analysis of the Columbia CO surveys. G.A.C. is an Alfred P. Sloan Research Fellow. This paper is Contribution 279 of the Columbia Astrophysics Laboratory.

Received 28 October; accepted 20 December 1984.

1. Raup, D. & Sepkoski, J. *Proc. natn. Acad. Sci. U.S.A.* **81**, 801-805 (1984).
2. Rampino, M. R. & Stothers, R. B. *Nature* **308**, 709-712 (1984).
3. Innanen, K. A., Patrick, A. T. & Duley, W. W. *Astrophys. Space Sci.* **57**, 511-515 (1978).
4. Davis, M., Hut, P. & Muller, R. A. *Nature* **308**, 715-717 (1984).
5. Bahcall, J. *Astrophys. J.* **276**, 156-168 (1984).
6. Thaddeus, P. *Ann. N.Y. Acad. Sci.* **395**, 9-16 (1982).
7. Allen, C. W. *Astrophysical Quantities*, 252 (Athlone, London, 1973).
8. Dame, T. M. & Thaddeus, P. *Bull. Am Astr. Soc.* **14**, 616 (1982).
9. Casoli, F., Combes, F. & Gerin, M. *Astr. Astrophys.* **133**, 99-109 (1984).
10. Bailey, M. E. *Mon. Not. R. Astr. Soc.* **204**, 603-633 (1983).
11. Sanders, D. B., Solomon, P. M. & Scoville, N. Z. *Astrophys. J.* **276**, 182-203 (1984).

A composite bolometer as a charged-particle spectrometer

N. Coron*, G. Dambier*, G. J. Focker†, P. G. Hansen‡, G. Jegoudez*, B. Jonson§, J. Leblanc*, J. P. Moalic*, H. L. Ravn†, H. H. Stroke|| & O. Testard¶

* LPSP, BP 10, F-91371 Verrières-le-Buisson, France
† EP-Division, CH-CERN, 1211 Genève 23, Switzerland
‡ Institute of Physics, University of Aarhus, DK-8000 Aarhus, Denmark
§ Chalmers University of Technology, S-41296 Göteborg, Sweden
|| New York University, Department of Physics, New York, New York 10003, USA
¶ Service d'Astrophysique, CEN, Saclay, F-91111 Gif-sur-Yvette, France

The measurement of radioactivity by direct conversion of nuclear radiation into a temperature rise of a calorimeter is as old as nuclear physics itself. As part of a general programme aiming at a determination of the mass of the electron neutrino, we have designed an improved version of a He-cooled composite diamond bolometer with a monolithic germanium thermistor, developed at the Laboratoire de Physique Stellaire et Planetaire (LPSP)[1]. Our approach, based on an idea by De Rujula[2], is to study the shape, near the upper end-point of the internal bremsstrahlung spectrum in electron-capture β decay. The best nucleus for a precise measurement seems to be ^{163}Ho, for which we have determined[3] the Q_{EC} value to be 2.83 ± 0.05 keV. A particularly interesting possibility is to use total absorption spectrometry[4] (calorimetry), in which the radioactive holmium forms part of the sensitive volume of the detector. With 5–6-MeV α particles impinging on the diamond wafer of the bolometer, a full-width-at-half-maximum (FWHM) of 36 keV was obtained at a temperature of 1.3 K. The theoretical resolution at 100 mK is a few electron-volts, so this new detection technique should give greatly enhanced energy resolution compared with present solid-state conductors based on charge carrier collection.

In 1903 Curie and Laborde[5] used a calorimeter to verify that the heat produced by a radioactive substance results from the absorption of its energetic radiation. After this, microcalorimetry became of great theoretical importance through the determination[6] of the 0.337-MeV average β energy of ^{210}Bi (Ra E). In fact, the contrast between this value and the maximum β-decay energy of 1.17 MeV for ^{210}Bi was one of the key arguments which led Pauli to the hypothesis of the neutrino. Microcalorimetry finally reached a sensitivity of $\sim 3 \times 10^{-5}$ W at 300 K[7]. It was Simon[8] who first pointed to the possibility of nuclear micro-calorimetry at low temperatures, where heat capacities are very low; Dalmazzone[9] has investigated a calorimeter at 1.8 K and reached a sensitivity of 10^{-9} W. The idea that bolometers or thermometers at low temperature could be used as detectors for radioactivity has reappeared

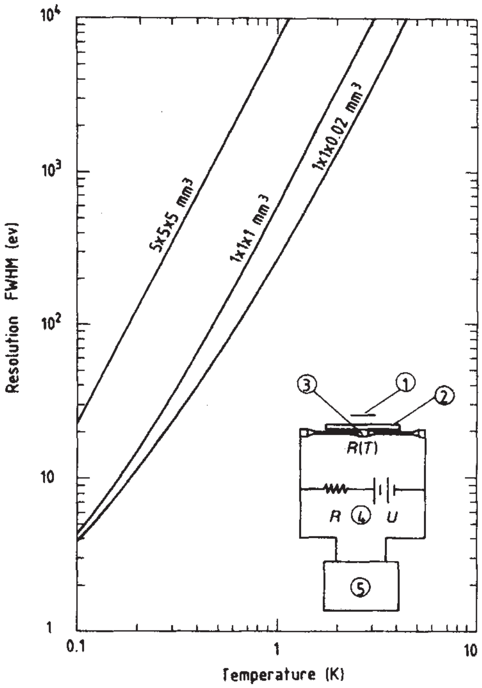

Fig. 1 Ultimate resolution with optimal filtering as a function of the temperature for the best available composite bolometer with a monolithic thermistor. The curves are calculated for three different detector volumes, V (mm^3), by means of the expression for Δv, given in the text. The 0.02-mm-thick detector represents the present technological size limit. The specific heat, C, is strongly material- and geometry-dependent and we have used the expression, $C = 7 \times 10^{-12} T^3 + 1.3 \times 10^{-12} T^{1.3} + 1.5 \times 10^{-12} T + 6.8 \times 10^{-11} VT^3$ as a good approximation to available measurements. The inset shows a schematic view of the experiment: (1) the α source; (2) the diamond substrate; (3) the Ga-doped Ge-thermistor, which also serves as mechanical support and thermal conductor to the 1.3 K thermostate; (4) the bias supply and the cooled load resistor; (5) the preamplifier-amplifier chain (at room temperature).

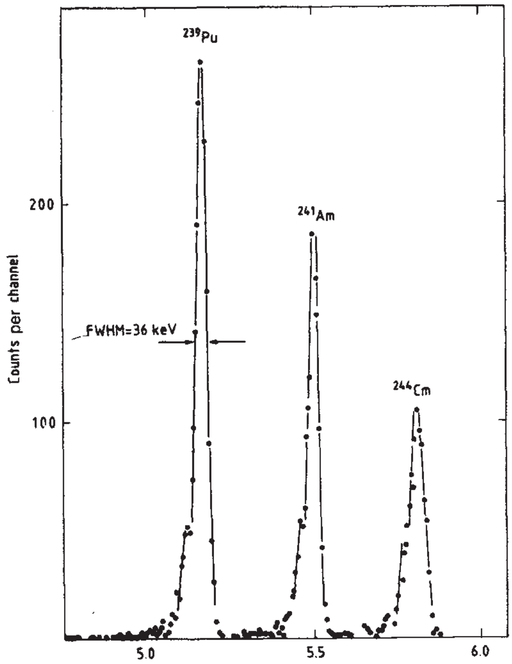

Fig. 2 Alpha energy spectrum from a mixed source of ^{239}Pu, ^{241}Am and ^{244}Cm, obtained by recording the thermal pulses induced by the α particles in a 0.25-mm^3 diamond bolometer. The resolution is 36 keV (FWHM) and the integral non-linearity is $< 10^{-3}$.